Acta Astronautica 108 (2015) 1–17

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Correlation of thermal mathematical models for thermal control of space vehicles by means of genetic algorithms

Eva Anglada [a,*], Iñaki Garmendia [b]

[a] TECNALIA. Industry and Transport Division, Mikeletegi Pasealekua, 2, E-20009 Donostia - San Sebastián, Spain
[b] Mechanical Engineering Department, University of the Basque Country UPV/EHU, Polytechnic School of Engineering, Plaza de Europa, 1, E-20018 Donostia - San Sebastián, Spain

A R T I C L E   I N F O

Article history:
Received 23 June 2014
Received in revised form
22 September 2014
Accepted 26 November 2014
Available online 11 December 2014

Keywords:
Model correlation
Thermal mathematical model
Space vehicle
Thermal control
Genetic algorithm

A B S T R A C T

The design of the thermal control system of space vehicles, needed to maintain the equipment components into their admissible range of temperatures, is usually developed by means of thermal mathematical models.

These thermal mathematical models need to be correlated with the equipment real behavior registered during the thermal test campaign, in order to adapt them to the real state of the vehicle "as built". The correlation of this type of mathematical models is a very complex task, usually based on manual procedures, which requires a big effort in time and cost. For this reason, the development of methodologies able to perform this correlation automatically, would be a key aspect in the improvement of the space vehicles thermal control design and validation.

The implementation, study and validation of a genetic algorithm able to perform this type of correlation in an automatized way are presented in this paper. The study and validation of the algorithm have been performed based on a simplified model of a real space instrument. The algorithm is able to correlate thermal mathematical models in steady state and transient analyses, and it is also able to perform the simultaneous correlation of several cases, as for example hot and cold cases.

1. Introduction

The environment conditions that must be borne by space vehicles are really extreme. During periods where the vehicle is in eclipse areas, temperatures are extremely low but during periods where the vehicle is exposed to solar fluxes, these arrive with high intensity due to the absence of atmosphere. Mechanical and electronic components, especially these last, are only able to operate into certain temperature ranges and they may suffer even irreversible damages if they go beyond their non-operating ranges of temperature. The mission of the thermal control system of any spatial vehicle is to maintain the equipment components into their admissible temperature ranges, in all the possible scenarios expected during the mission.

The design of the thermal control system is usually developed by means of the geometrical mathematical model (GMM[1]) and the thermal mathematical model (TMM). The GMM is used to calculate the radiative links between the nodes that represent the spacecraft and its results are included in the TMM. The TMM is a mathematical model representative of the thermo-structural configuration of the space vehicle, allowing the analysis of its thermal behavior under different operating conditions. It makes it possible to

* Corresponding author. Tel.: +34 667 119 553.
E-mail addresses: eva.anglada@tecnalia.com (E. Anglada), inaki.garmendia@ehu.es (I. Garmendia).

[1] See "Nomenclature".

http://dx.doi.org/10.1016/j.actaastro.2014.11.042
0094-5765/

Nomenclature

ΔT	global temperature deviation
λ	maximum variation coefficient
a	a real number
b	a real number
C_i	chromosome i
f	fitness value
i	an integer number
J	number of cases
K	number of instants of reference
N	number of temperature points or nodes considered for correlation
p_c	crossover probability
p_m	mutation probability
p_s	selection probability
$T_{calculated}$	temperature calculated
$T_{reference}$	temperature of reference
T_{M_i}	measured temperature
T_{P_i}	calculated temperature
APSO	adaptive particle swarm optimization
DLL	dynamic link library
EuTEF	European Technology Exposure Facility
ESA	European Space Agency
PC	personal computer
GA	genetic algorithm
GL	linear conductances
GMM	geometrical mathematical model
GR	radiative conductances
ISS	International Space Station
MC	nodal thermal capacities
RCGA	Real-Coded Genetic Algorithms
RWS	roulette wheel selection
Target	correlation value target
TK	software for heat transfer analysis
TMG	software from Maya HTT Company
TMM	thermal mathematical model

predict the temperature distributions along the equipment and also the heat exchange with the environment.

The design and the built up of the thermal control system is later verified during the thermal test campaign, which any spatial vehicle must overcome. Thermal tests also permit the later correlation of the TMM, in order to adapt it to the real behavior registered during the thermal test execution of the space vehicle “as built”.

The TMM correlation is a very complex task. Although a wide range of optimization techniques exist that can be applied to automatize the TMM correlation, the established practice is the manual correlation. See Ref. [1] for an example of the TMM manual correlation of a real space vehicle. This is done due to the complexity of the mathematical problem. The number of input/output parameters is usually high and, in addition, the models are not linear due to radiation terms. The TMM manual correlation requires a big effort in time and cost, and impedes to achieve the correlation in real or quasi-real time during the thermal test execution. For these reasons, the development of methodologies able to advance in the automatized TMM correlation would be an important aspect in the improvement of the thermal control design and validation.

The number of previous works focused on automatized thermal mathematical models correlation is quite reduced, and even more reduced for the specific case of the space vehicles TMMs. The European Space Agency (ESA) funded several research activities in this area in the past, see [2–5], which state a very interesting scenario. Thanks to the advances in calculation capacities, the TMM correlation was tackled by means of stochastic techniques of optimization, specifically by the use of genetic algorithms (GA). Results obtained by this technique were promising but they also revealed the necessity of more research efforts in this area, until reaching a methodology solid enough to be used in spatial projects.

More recently one method for the estimation of the thermal mathematical model of a space vehicle based on Kalman filters was presented in [6]. However, the work was not focused on the TMM correlation with thermal test but dealt with an adaptive modeling of the vehicle once in orbit, which is based on data registered during the mission. Kalman filters are widely used for adaptive models estimation, and in this work the temperatures and parameters that define the thermal characteristics of the model are considered state variables and the state equations of the thermal mathematical model are derived from them.

The work presented in [7], deals with the correlation of space vehicle TMM and thermal tests by means of adaptive particle swarm optimization (APSO) techniques. In this case, the goal to be optimized is a fitness function defined in a multidimensional search space. The swarm is formed by a series of particles where each one represents one possible solution to the problem and whose fitness is evaluated on each algorithm iteration. Basically, the position of the swarm population is updated after each iteration by means of a displacement vector dependent of the previously obtained solution.

The work presented henceforward continues the promising research line based on genetic algorithms, previously studied by the ESA, with the objective of contributing to the development of this research line in the search of a methodology solid enough to be used in space projects. The implementation, study and validation of a GA, an in-house development to carry out the TMM correlation are presented hereafter.

2. Methodology

The genetic algorithm specifically designed to perform the automatized correlation of a space vehicle TMM is presented. First a short description of the thermal mathematical model used to validate the algorithm is included, followed by the description of the developed algorithm.